

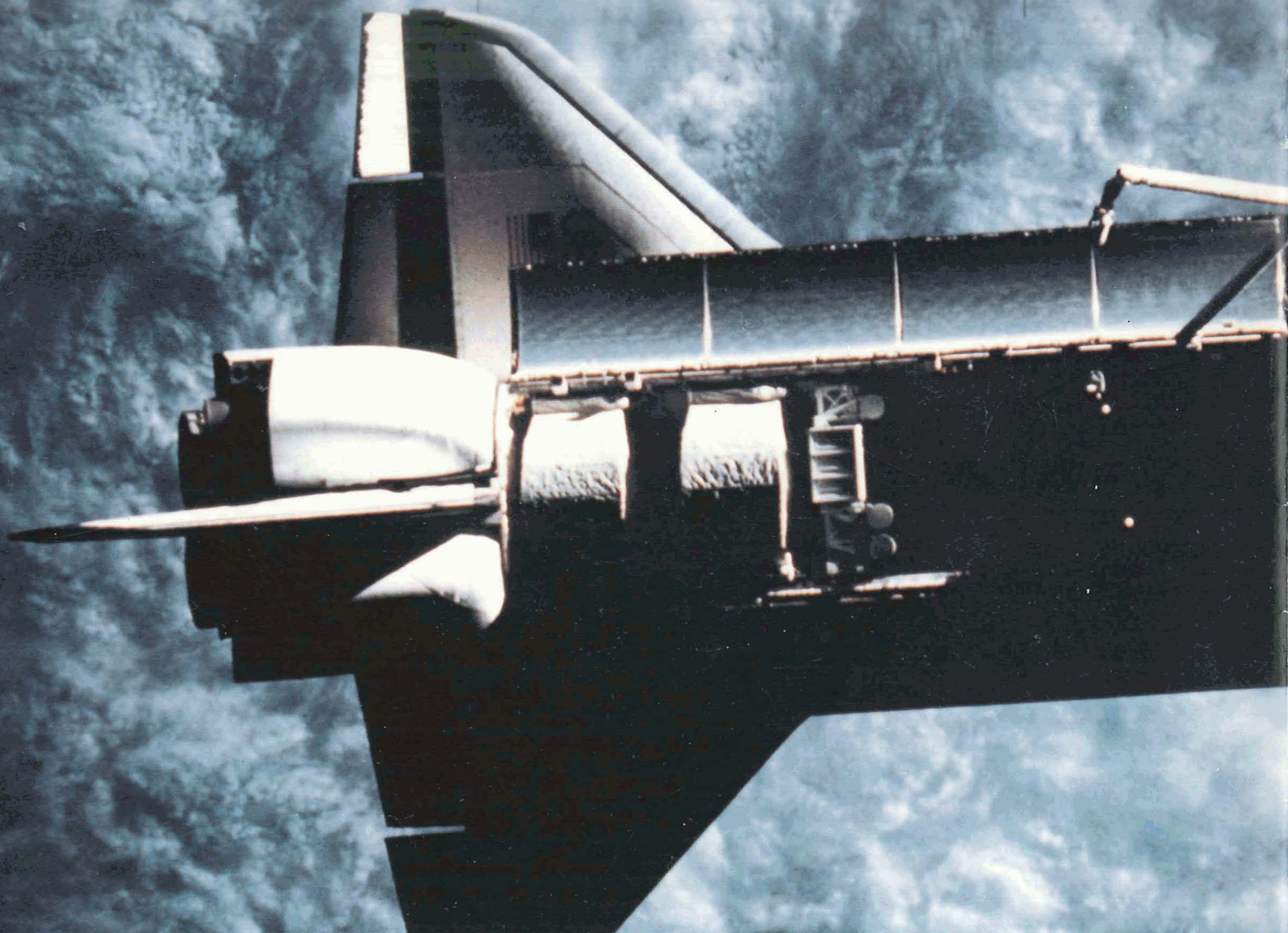
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Microgravity

...a new tool for basic and
applied research in space

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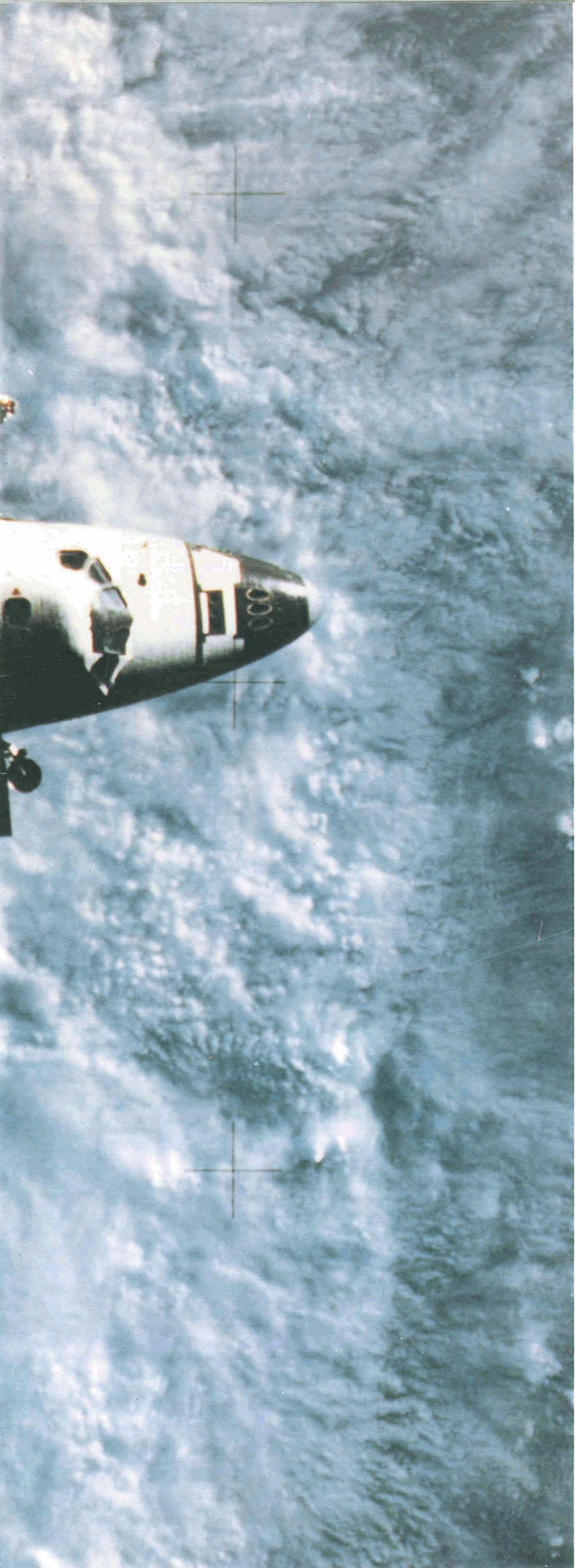


The OSTO-2 payload with the first Materials Science experiments is in the center of the Shuttle cargo bay (June 1983).

This brochure highlights selected aspects of the NASA Microgravity Science and Applications program. So that we can expand our understanding and control of physical processes, this program supports basic and applied research in electronic materials, metals, glasses and ceramics, biological materials, combustion and fluids and chemicals. NASA facilities that provide weightless environments on the ground, in the air, and in space are available to U.S. and foreign investigators representing the academic and industrial communities.

After a brief history of microgravity research, the text explains the advantages and methods of performing microgravity research. Illustrations follow of equipment used and experiments performed aboard the Shuttle and of prospects for future research. The brochure concludes by describing the program goals and the opportunities for participation.

To obtain more detailed information about the Microgravity Science and Applications program, please write to Mr. Richard E. Halpern, Code EN-1, NASA Headquarters, Washington, DC, 20546, or call (202) 453-1490.



Microgravity

... a new tool for basic and
applied research in space

Microgravity Science and
Applications Division

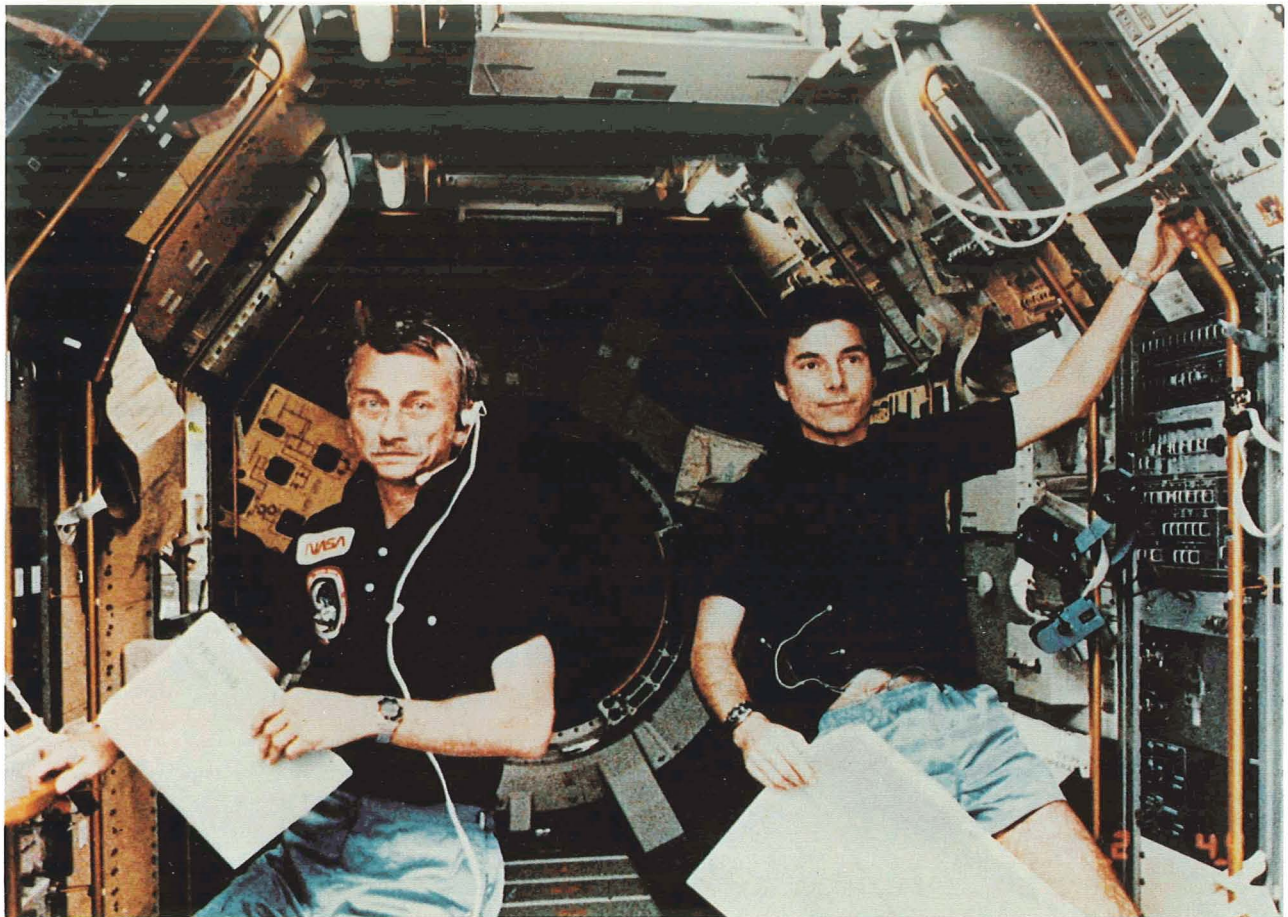
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Astronaut Owen K. Garriott (left) and Payload Specialist Ulf Merbold (right) take data for experiments on Spacelab I.

Program Evolution

From the beginning of the space program, NASA has had a special interest in the effects of weightlessness. Some of NASA's earliest studies were directed at propellant systems for rockets and structural welding in space. Initially, these studies were conducted in drop towers on Earth. Weightlessness lasted only 5 to 10 seconds. By the mid-1960s, however, the brief periods of weightlessness available in drop towers or on aircraft flights gave way to the longer microgravity experiments of the Apollo program. Microgravity experiments were also conducted on Skylab and the Apollo-Soyuz project, jointly operated by the United States and the U.S.S.R. Most recently,

microgravity research has taken place on the Space Shuttle.

The Space Shuttle opened a new era in microgravity science and applications. While opportunities for reflight and recovery of test samples were available before the Shuttle, the Shuttle permitted larger and more complex experiments than ever before. This combination of heavier payloads and repeated missions allows NASA to expand scientific and commercial research in space. For the 1980s and beyond, space-based microgravity research, especially materials processing, will be one of the centerpieces of the U.S. space program.

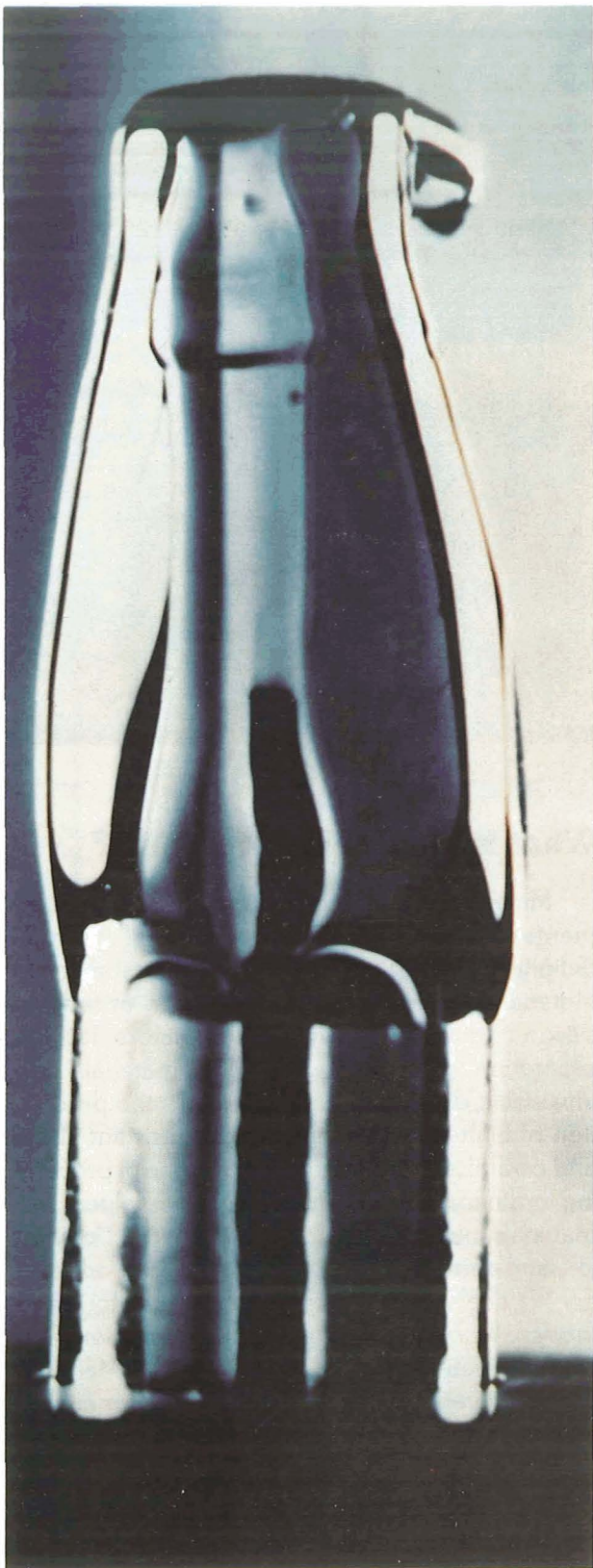


An aluminum-calcium oxide pellet is heated, melted, and resolidified while suspended by airflow.

What is Materials Processing?

Materials processing is one of the central elements of NASA's microgravity program. A simple definition cannot adequately explain the term. Materials processing is the conversion of sand to silicon crystals for use in semiconductors. It is the separation of ordinary biological materials into invaluable drugs and chemicals. It is the production of high-strength, temperature-resistant alloys and ceramics. It is, in short, the science of processing ordinary and comparatively low-valued raw materials into crystals, chemicals, metals, ceramics, and countless other manufactured products.

Materials processing enables us to build modern computers to process information and communications systems to transmit it. Materials processing enables us to build turbines for aircraft and electric power plants. Materials processing makes possible revolutionary advances in the production of chemical and biological compounds, such as insulin. And, not surprisingly, materials processing, by producing high-strength alloys and heat-resistant ceramic tiles, makes the space program possible.



This nearly flawless, single crystal of indium-antimonide was grown on Skylab.

Why in Space?

Just as materials processing on Earth made the leap into space a reality, the space program today offers unique opportunities for materials processing. The most important benefit of processing in space is extended weightlessness. On Earth, gravity causes materials of different densities and temperatures to separate and materials to deform under their own weight. In the microgravity of an orbiting spacecraft, however, scientists can use unique materials processing techniques, techniques that are all but impossible on Earth. The results may lead to a material or a processing approach of scientific or commercial value.

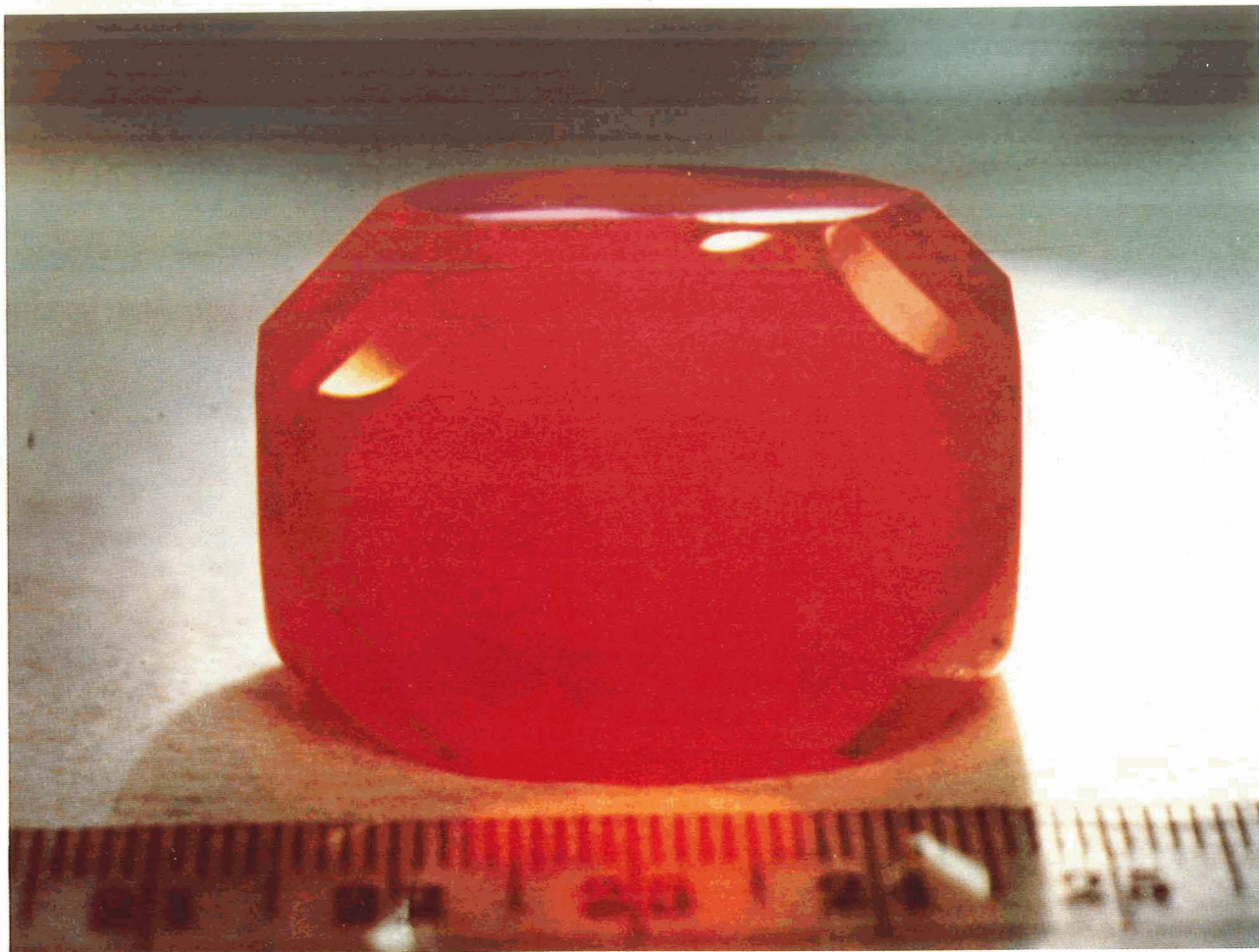
Among the commercial, scientific, and military benefits of space-based processing are the following:

Electronic materials (crystals). Pure, nearly perfect crystals are required in computers, lasers, and numerous other optical and electronic devices. Space processing permits crystal purity and uniformity far beyond those possible on Earth.

Metals, glasses, and ceramics. High-strength metals and temperature-resistant glasses and ceramics are essential to power generation, propulsion, aviation, aerospace, and related applications. Containerless processing in space permits scientists to mix and solidify metals and ceramics in forms and at levels of purity that cannot be obtained on Earth and offers a better understanding of solidification processes on Earth.

Biological materials. Separation of macromolecules (proteins, enzymes, cells, and cell components) is fundamental to all fields of biological research. Weightless processing permits scientists to separate and purify biological materials more effectively than can be done on Earth.

Fluids and chemicals. Virtually every physical science depends on an understanding of the effects of gravity on convection, buoyancy, sedimentation, and the like. Investigations of fluid physics and combustion processes under weightlessness can help reveal subtle interactions among atoms and molecules that are not observable under normal gravity.



This mercuric iodide crystal was grown on Earth. Another will be grown in space, on Spacelab 3.

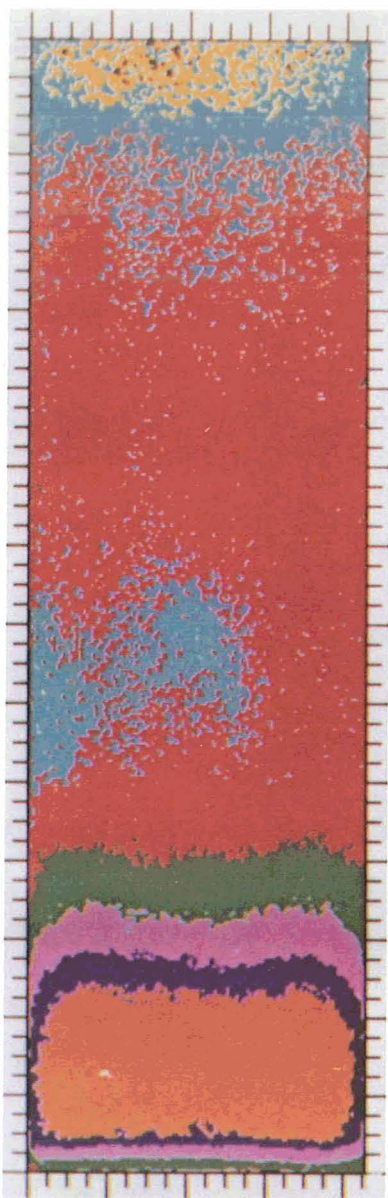
Electronic materials

Crystals are at the heart of the electronic revolution. Crystals, made of silicon or other materials, are the basis for semiconductors, computers, radiation sensors, and lasers. Crystals enable us to operate satellites for worldwide communications, weather reconnaissance, and military surveillance. Crystals allow us to explore frontiers — for example, artificial intelligence — that were once thought unreachable.

The structure and purity of the crystals that support these technologies are remarkable. Impurities measured in the parts per billion can render a crystal useless. Structural defects at the molecular level can have the same effect. On Earth, these problems are partially overcome only

with complex and costly processes for growing crystals and obtaining the desired electrical properties. Space offers at least two highly desirable conditions for crystal growth:

- Weightlessness permits scientists to grow large, nearly perfect crystals. Gravity-driven flows that deform the face of the growing crystal or distort the crystallizing zone are absent in a weightless environment.
- In a weightless environment, objects like crystals can be processed without a container. Containerless processing permits scientists to melt and solidify crystals without the crystals absorbing impurities from a container.



On Earth, gold is mixed into lead by gravity-induced convection in both the stable (left) and unstable (right) orientations.

Metals, glasses, and ceramics

If crystals provide the electronic basis for the future, metals, glasses, and ceramics provide the structural bases. Advanced metals, glasses, and ceramics are essential to such products as jet engines, nuclear power plants, electro-optical devices, and the Space Shuttle itself.

In the case of the Space Shuttle, for example, the heat of reentry (up to 3,000°F) is enough to destroy every metal known. The solution? A ceramic made of silica fibers, offering exceptional

heat resistance. When formed into a tile at high temperature and low pressure, the silicon fiber becomes a low-density solid that resists the heat of reentry. Such ceramics offer a wide range of opportunities for high-temperature applications.

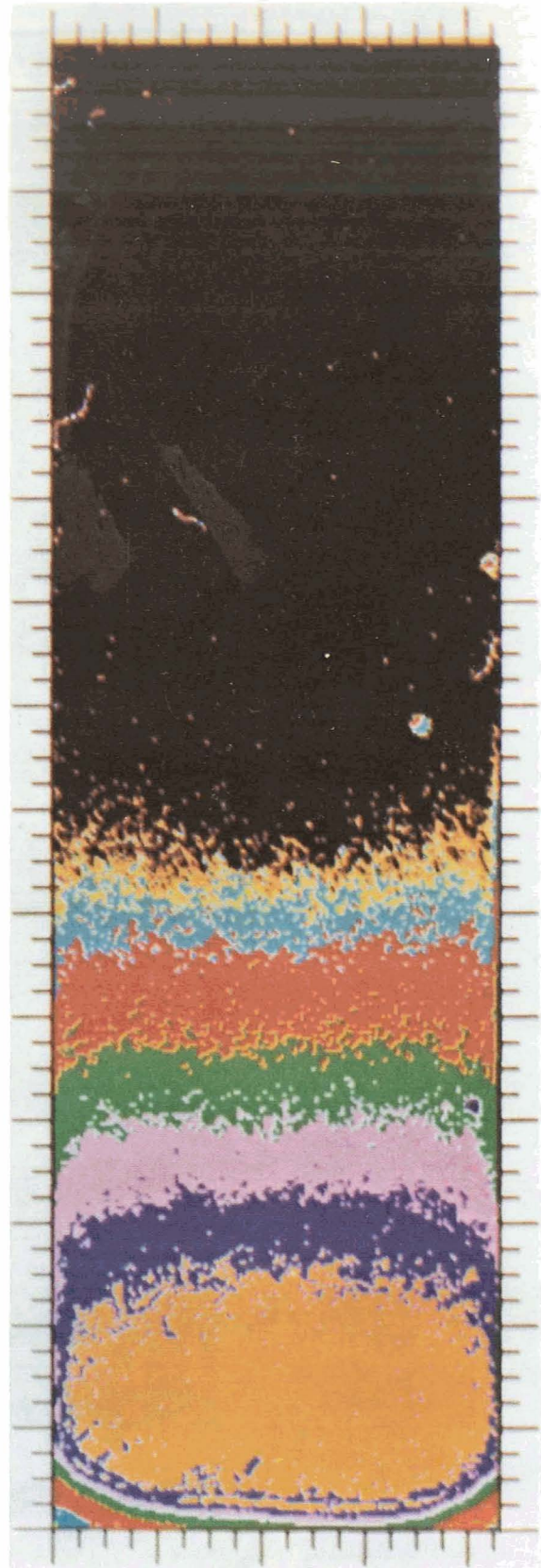
Where high temperatures are combined with high stress, however, ceramics can crack. For these types of applications, including the turbine blades of jet engines, special metals are needed. These metals are cast under exacting conditions to ensure the precise structure required.

The weightlessness of space offers scientists an opportunity to investigate and improve the methods for creating advanced metals, glasses, and ceramics. While no one expects giant space foundries to turn out quantities of manufactured products in the near future, scientists do expect this research to uncover compounds whose properties are of great value.

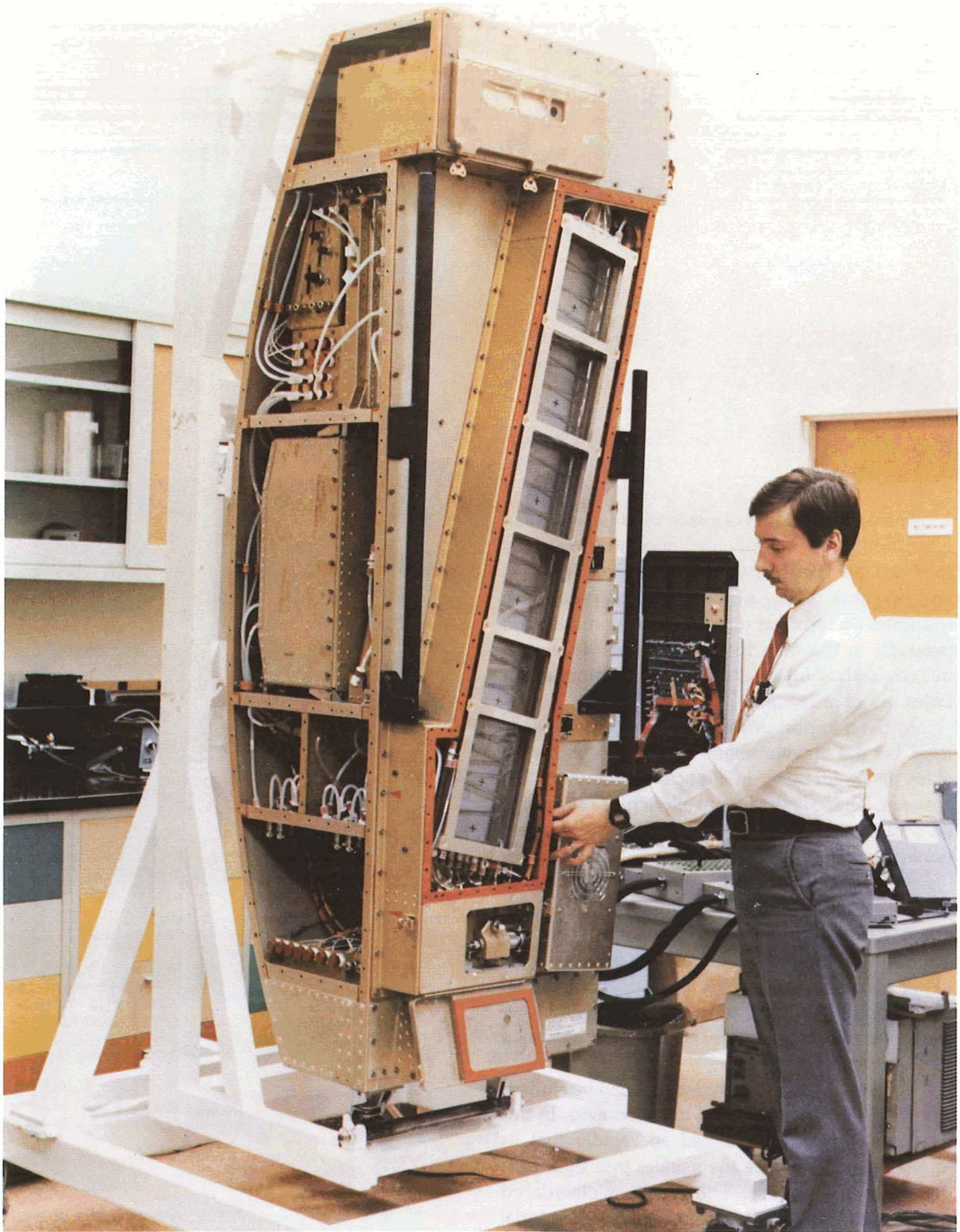
Another important benefit of space processing may be the development of lower-attenuation glass fiber for use in optical communication systems. These fibers would allow more signals to be sent over a longer distance than do conventional fibers.

Among the important manufacturing methods that could benefit from weightlessness is directional solidification. Under directional solidification, metals can be given enhanced properties along a preferred direction. For applications that place great strain on the metal in a known direction, as in a turbine engine, directionally solidified metals are invaluable.

Another important process that can be studied extensively in space is rapid undercooling. In this process, a metal is solidified so rapidly that its atoms cannot organize themselves into their normal metallic structure. The result, a disordered structure similar to that of glass, gives the material unusual properties. This process, studied in space, is advancing casting technology on Earth.



In space, the gold diffuses into the lead.



Continuous flow electrophoresis apparatus undergoes ground tests.

Biological materials

One of the most exciting areas of microgravity research is biological materials processing. Processing biological materials typically requires separating specific cells, cell components, antigens, hormones, and proteins from a biological medium.

On Earth, one of the most widely used analytical technologies is electrophoresis. In electrophoresis, a gel or another supporting medium is used to suppress convective flows. Small batches of materials are separated by differences in net electrical charge, size, and shape. Positive and negative potentials are applied to either end of a medium containing the materials to be separated. As the electrical potentials are applied, materials migrate through a gel or other supporting media toward the attracting potential. Scientists can then concentrate some of the desired materials.

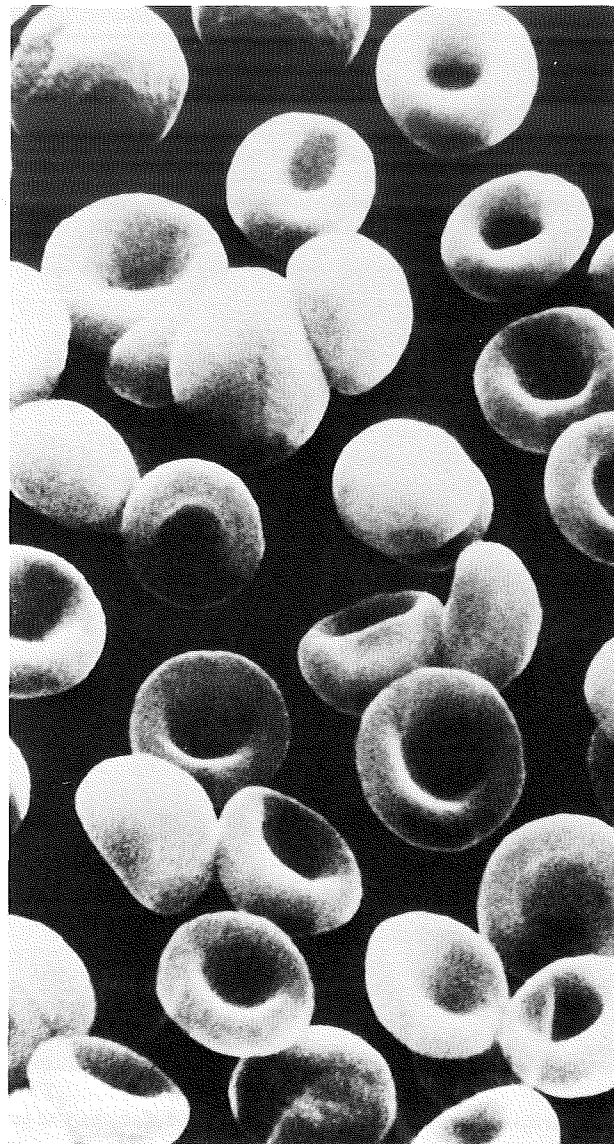
To extend this process to a preparative scale or to apply it to cells, cell components, or other particles, the supporting medium must be eliminated. Such "free-flow" electrophoresis techniques have met with limited success on Earth because of gravity-driven convective flows, which tend to remix the separated components.

In space, the convective flows are virtually eliminated. Separation techniques such as continuous flow electrophoresis (CFE) permit separation of biological materials in quantities and levels of purity unattainable on Earth.

In CFE, which is efficient only in a weightless environment, a continuous flow of biological material is separated. Without the effects of gravity to distort the separation process or the separation medium, gels or other supporting media are no longer required. Larger quantities of purer materials can be produced. Cells and cell components that would not pass through the pores of the gel can be separated in space by this process. The potential commercial benefit of space-based CFE is sufficient that a U.S. industrial consortium has already sponsored a commercial CFE experiment aboard the Shuttle.

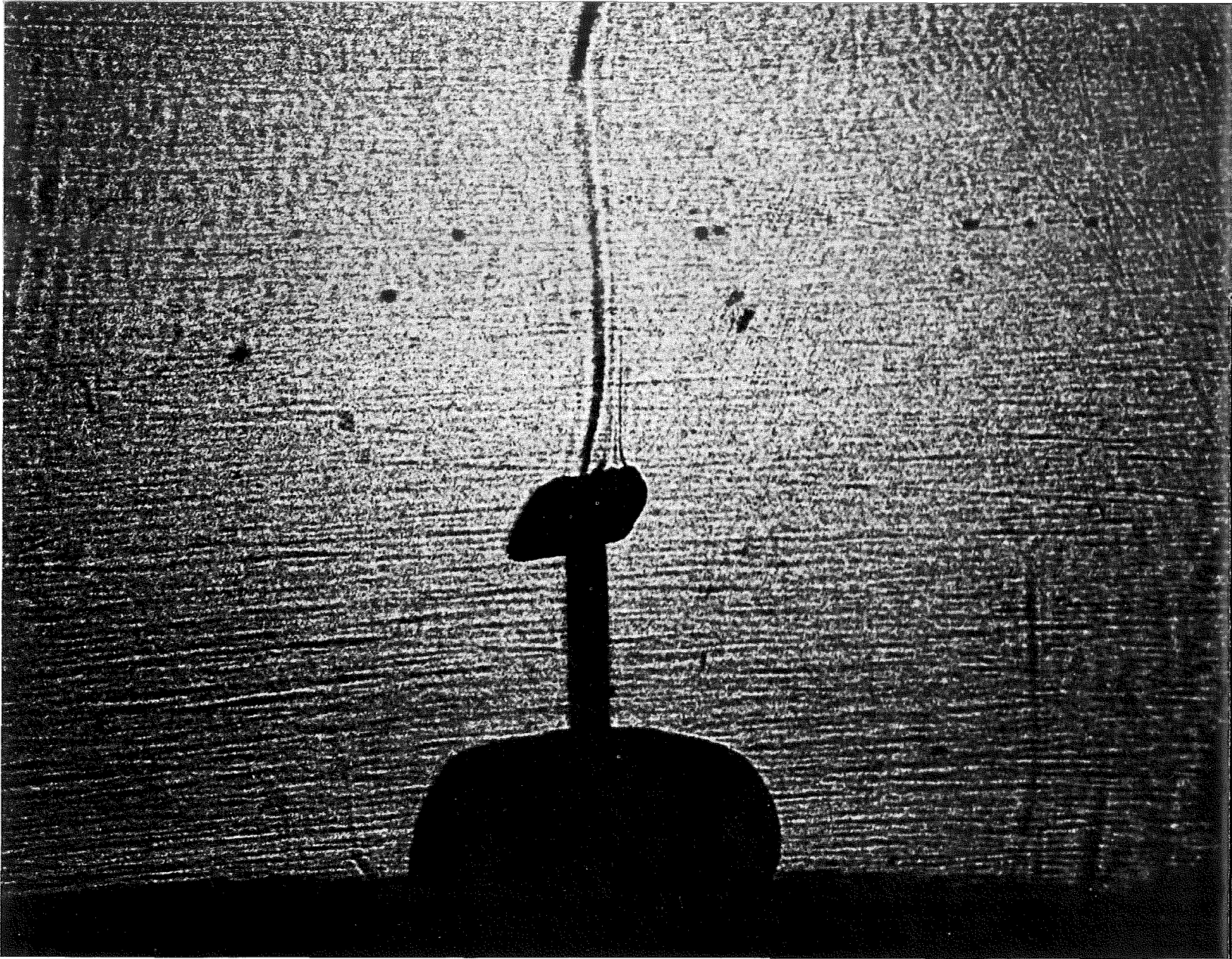
The potential benefits from weightless electrophoresis and other biological materials processing techniques are enormous.

The importance of biological materials processing in space can be understood by considering



Electrophoresis in space can be used to separate blood cells.

the quantities and values of desired materials. On Earth, many essential biological materials can be produced only in gram or milligram quantities and then only at costs of tens of thousands of dollars per unit. The value of these materials per unit of weight and the ability to produce greater quantities in the weightless environment of space mean that commercial-scale production in space may prove to be very economical. In addition to commercial-scale production of proven materials, space offers the opportunity for extended research into new and promising biological techniques commercially unattainable in the gravity on Earth.



A gravity-driven plume of less dense liquid disturbs the growth conditions around a crystal.

Fluids and chemicals

What are fluid processing and chemical processing? Unlike crystal growth or biological materials processing, fluids and chemicals seem quite ordinary.

But consider the areas of interest to microgravity researchers in fluids and chemicals:

Blood flow. Gravity prevents certain measurements of blood viscosity. These measurements may be possible in space.

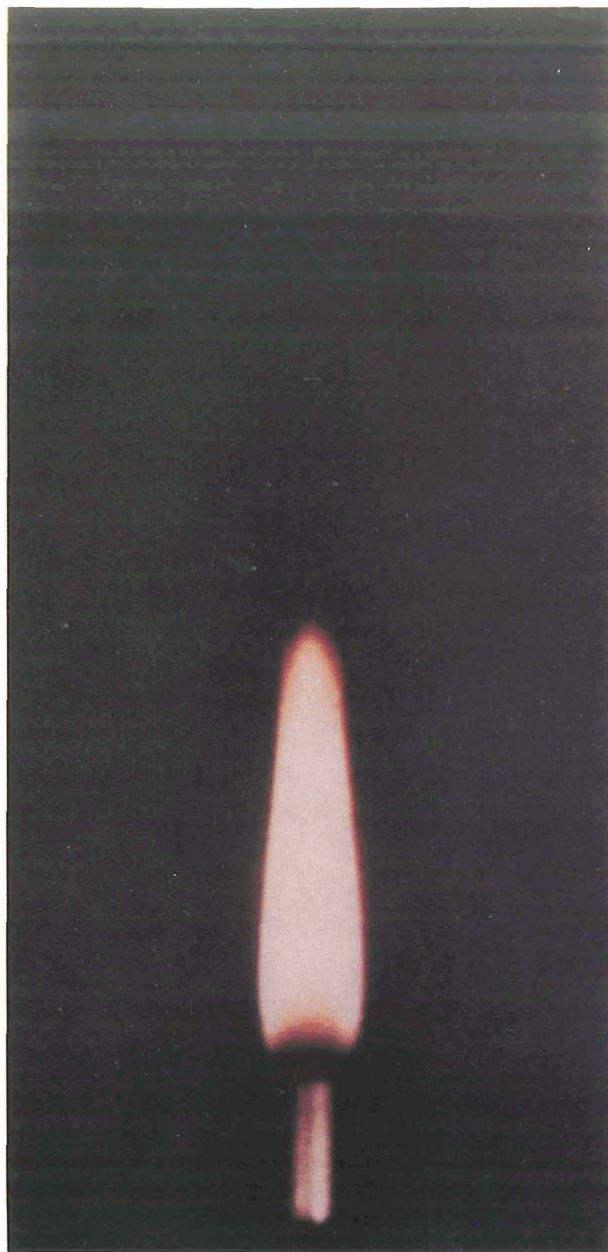
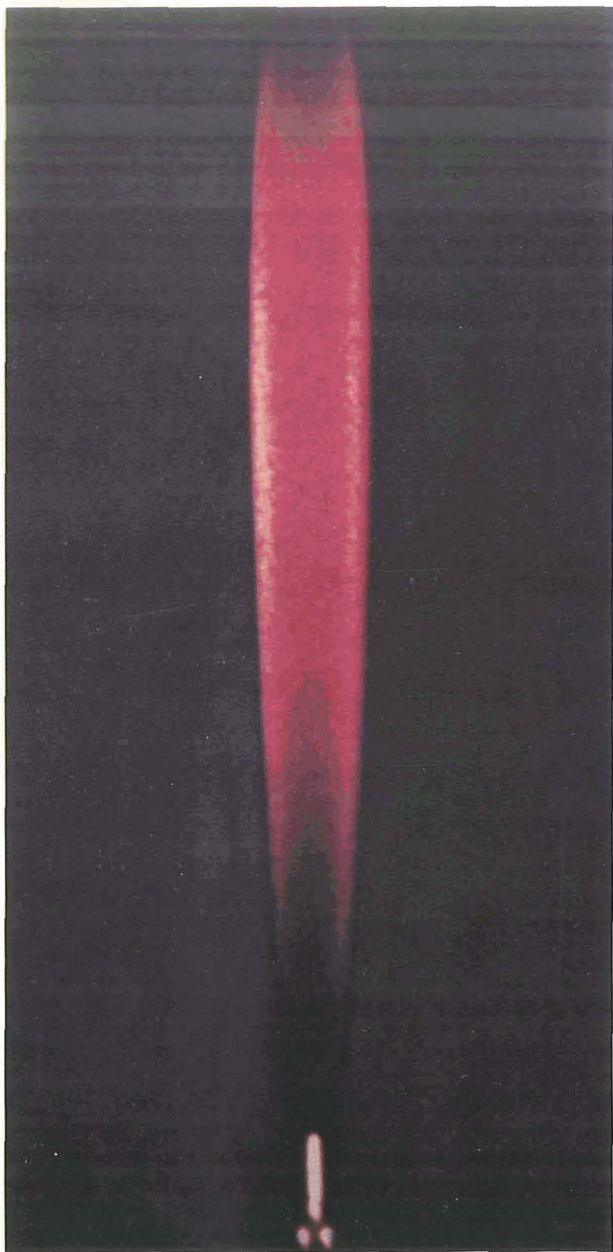
Combustion systems. A better understanding of fundamental combustion mechanisms can be achieved in the absence of gravity-induced convection.

Fluid spreading. How do liquid films used as lubricants and surface coatings spread over solids?

Corrosion. It is unclear how certain metallic compounds, such as rust, precipitate out of solution. A weightless environment may reveal the processes and possible ways to inhibit them.

Organic crystals. Can certain desirable organic crystals, such as proteins, be grown more efficiently in space?

Pollution control. How do pollutant particles come together and bind to one another? How can they be bound to other particles?



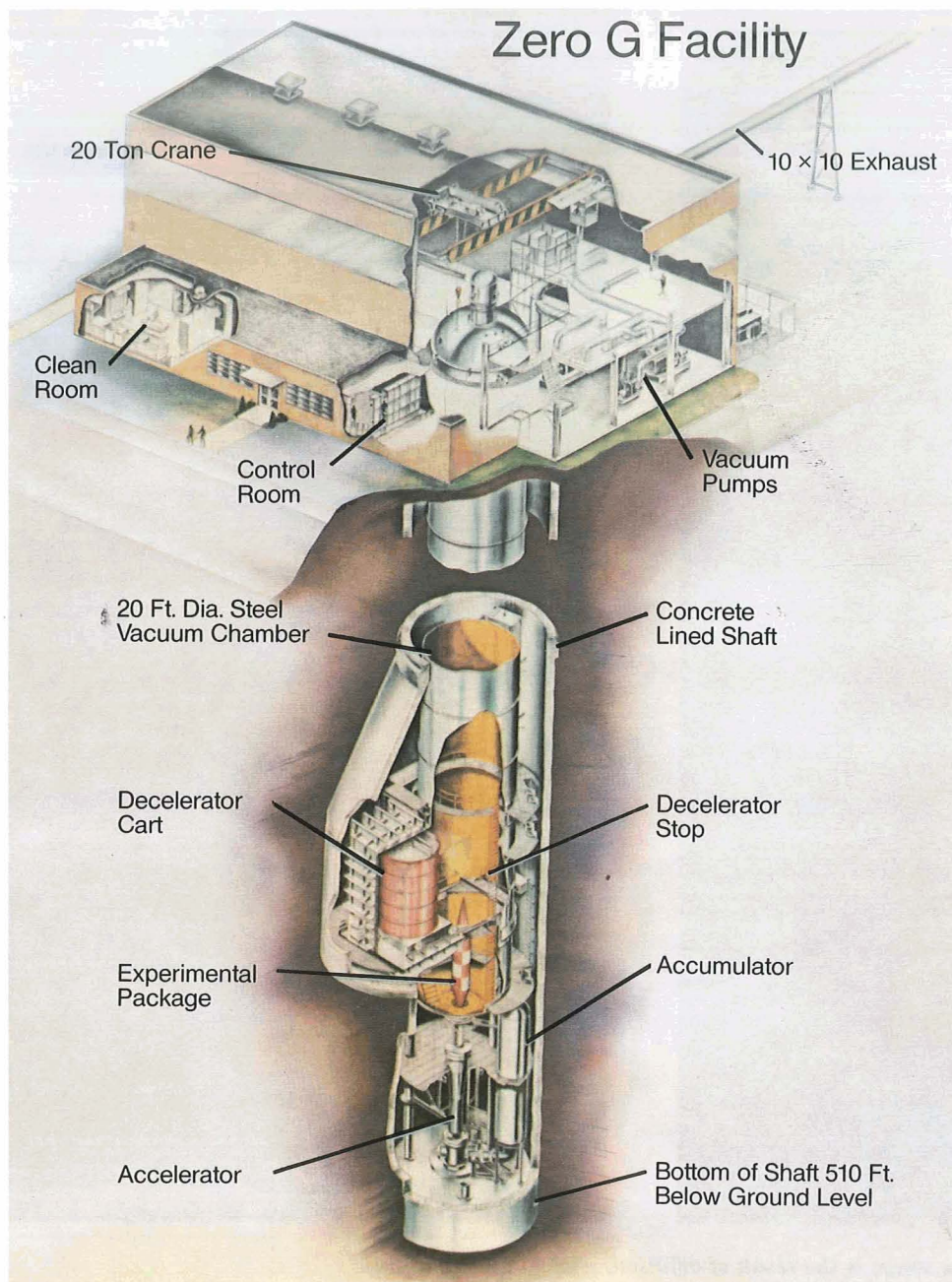
In zero gravity (left), the flame shape is the result of diffusion, while on Earth (right) gravity-induced convection produces the more familiar flame.

The potential benefits of finding answers to these questions are substantial. Microgravity research permits scientists to eliminate gravity-driven forces and to concentrate on much more subtle interactions, such as diffusion, solubility, and capillary action.

Take combustion, for example. Combustion produces light, hot gases that rise rapidly under normal gravity. Convection from these rapidly rising gases alters the initial distribution of fuel and

oxidant in the combustion chamber. These convective forces mask the role of diffusion and other fundamental processes in flame propagation and solid surface combustion. Understanding the fundamental combustion processes in microgravity will directly contribute to our ability to use fuels *on Earth* more efficiently and with reduced production of pollutants.

Similar benefits are possible in microgravity investigations of other fluid and chemical processes.

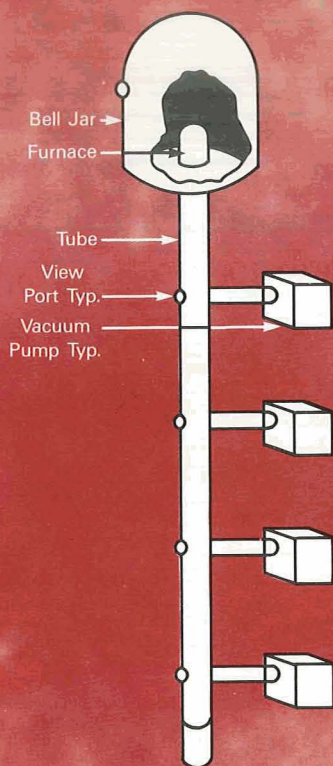


The 155-meter Zero-Gravity Facility at NASA's Lewis Research Center provides five seconds of weightlessness.

How is it Done?

Weightlessness is not strictly the absence of gravity, but rather the lack of relative motion among objects in a freely falling enclosure. For example, if a man standing in an elevator drops a coin, the coin falls to the floor. If the elevator cable breaks, however, and the elevator begins to fall, a dropped coin will literally float. The coin will float

(relative to the man and the elevator) because the elevator and everything within it will be in a state of free fall. This principle of relative motion can be used to simulate weightlessness on the ground (drop towers and drop tubes); in the air (research aircraft); in space (sounding rockets); in orbit aboard the Shuttle; and, in the near future, aboard the NASA Space Station.



Small droplets are solidified during three seconds of weightlessness in the 100-meter drop tube at the NASA Marshall Space Flight Center.

On the ground...drop towers and drop tubes

On the ground, drop towers and drop tubes are used to obtain a few seconds of weightlessness. In a drop tower, experiments are placed in a canister at the top of the tower and dropped. As the canister freely falls downward, its contents become weightless; that is, there is no resistance to the acceleration of gravity. As with the coin in the falling elevator, there is no relative motion among the items in the canister. During these few seconds of weightlessness, scientists can, for example, mix and solidify compounds that rapidly separate

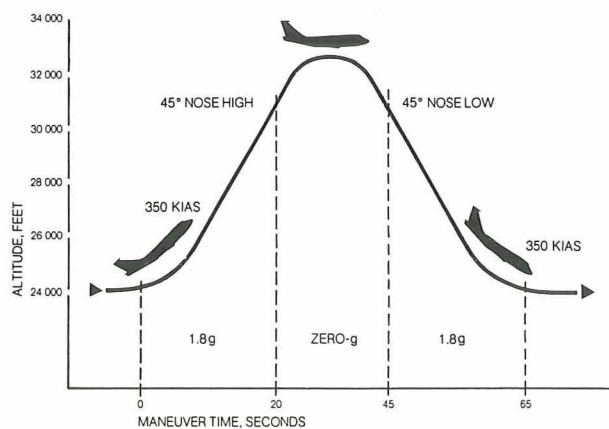
under normal gravity and can study fluid phenomena independent of gravity-driven convection.

A drop tube is simply a long vacuum tube. Millimeter-sized samples are melted and allowed to solidify as they fall. Because the tube itself contains a vacuum, no canister or other "drag shield" is required. Containerless solidification can be studied in such a facility.

Drop towers and drop tubes offer the opportunity to test concepts through brief, small-scale experiments. Experiments requiring more than a few seconds of weightlessness must be performed in other facilities.



The NASA KC-135 aircraft enters a parabolic trajectory that provides up to 30 seconds of weightlessness.



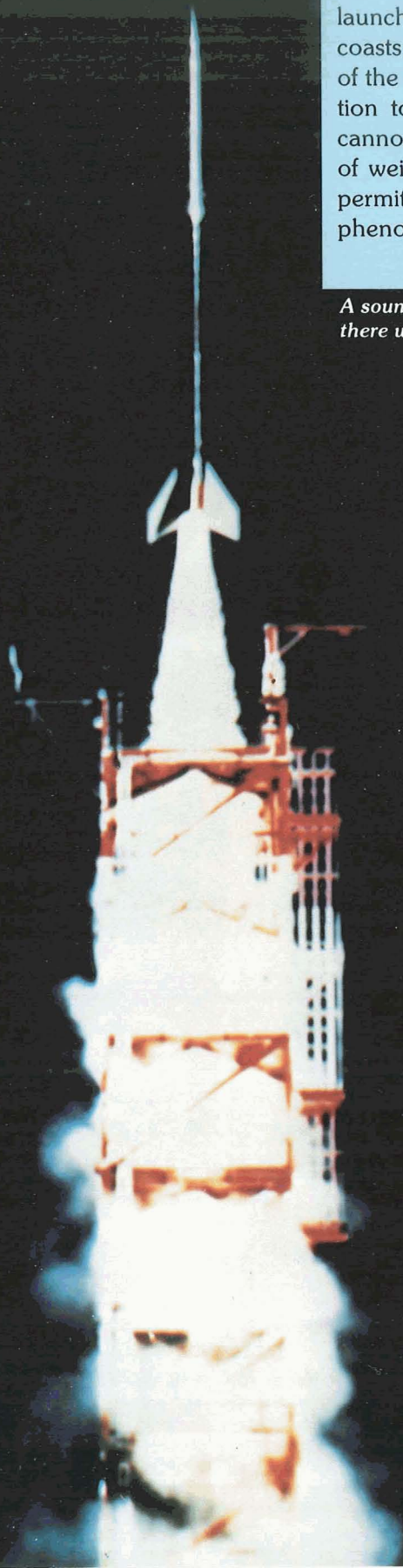
In the air...research aircraft

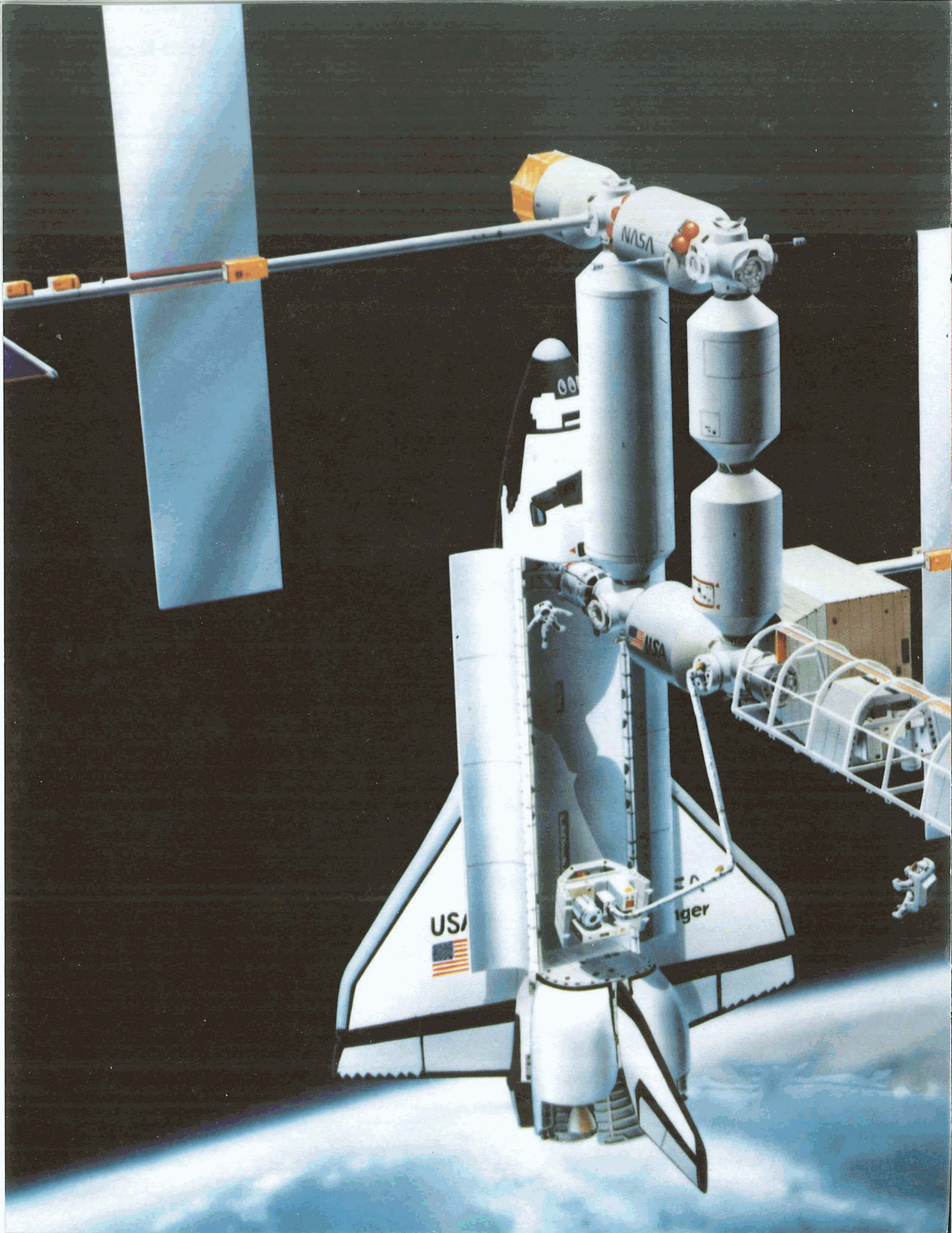
In the air, weightlessness can be obtained inside a plane flying a parabolic trajectory. To fly this type of trajectory, the plane climbs rapidly at a 45° angle (termed pull-up), slows as it traces a parabola (pushover), and then descends at a 45° angle (pull-out). The forces of acceleration and deceleration produce twice normal gravity during the pull-up and pull-out legs of the flight, while the brief pushover at the top of the parabola produces less than one percent of the Earth's gravity. This airborne weightlessness lasts for 20 to 30 seconds. In most cases, the aircraft is flown up and down like a roller coaster, so that repeated 20- to 30-second periods of weightlessness can be achieved. In an aircraft, however, the variability of the reduced gravity makes precise experimentation difficult.

In space...sounding rockets

For small experiments, up to five minutes of weightlessness can be obtained by using suborbital rockets. These rockets, called sounding rockets, launch a small payload into space. As the payload coasts upward and falls back to Earth, the contents of the payload are motionless (weightless) in relation to each other. Although sounding rockets cannot be used for large experiments, the duration of weightlessness produced by the suborbital fall permits scientists to explore a wide range of phenomena.

A sounding rocket is launched on a flight during which there will be up to 300 seconds of weightlessness.







In space...orbiting spacecraft

Experiments that require extended periods of weightlessness can be performed aboard orbiting spacecraft, like the Shuttle and Spacelab. Contrary to popular belief, the weightlessness in an orbiting spacecraft is not caused by the absence of gravity. Without gravity, the spacecraft would not follow a circular orbit, but would take off on a tangent, just as a stone is propelled from a slingshot. The weightlessness is caused by the spacecraft continuously falling toward Earth, but with its forward motion continuously redirecting its path. This redirected fall (the spacecraft's orbit) creates a nearly perfect environment for extended microgravity research.

Beyond the Space Shuttle and Spacelab, NASA is now planning a manned orbiting Space Station. The Space Station will be able to support microgravity investigations in pressurized laboratory modules on externally mounted pallets or on co-orbiting free-flying platforms. These space facilities, with weightless periods measured in months and years instead of the hours, minutes, and seconds available so far, will create new and greater opportunities for microgravity research.

The artist's concept of the NASA Space Station depicts a payload being transferred to the station for a long-duration experiment in the space environment.

Research Equipment Aboard the Shuttle

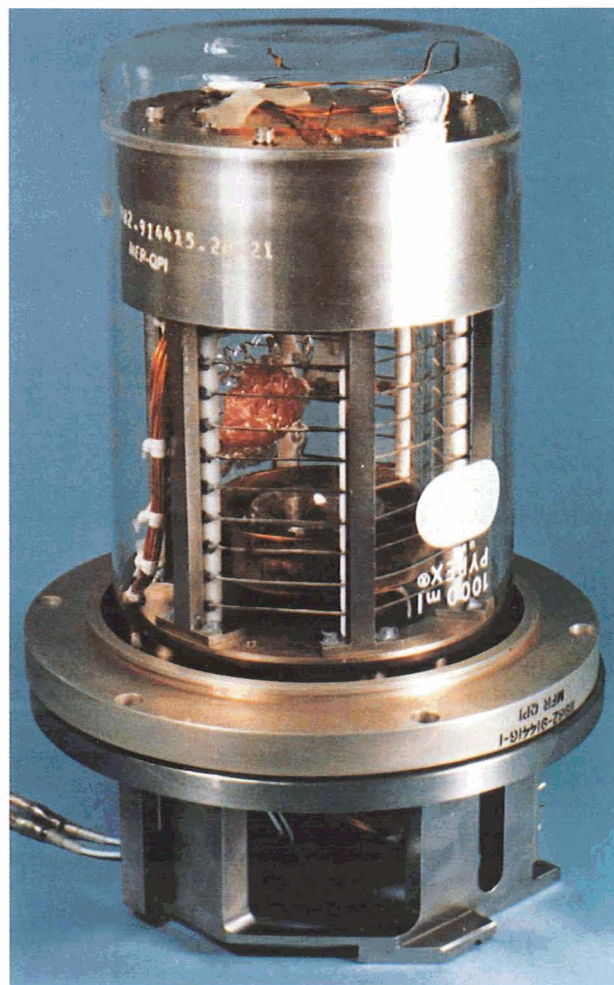
At present, the principal means of conducting orbital research is via NASA's Space Shuttle. Experiments aboard the Shuttle may be conducted in the middeck area of the Orbiter cabin, in the cargo bay, using either the Materials Experiment Assembly or the Materials Science Laboratory; and in the Spacelab module. Each of these Shuttle payload areas offers certain special characteristics.

Middeck payloads are carried in one or more of the 42 middeck storage lockers, each about 2 cubic feet in size with a maximum experiment weight of 60 pounds. Crew involvement with mid-deck experiments is possible.

Payloads using the Materials Experiment Assembly are self-contained and operate independently of the Shuttle itself. Payloads on the Materials Science Laboratory (MSL) use the resources provided by the Orbiter. The experiments can be large (up to 12 cubic feet [on an upcoming flight]) and heavy (up to 2,100 pounds [on the same flight]). The total weight of the experiments in the laboratory is more than 3,300 pounds.

Spacelab experiments are similar to MSL experiments in size and character, except that the crew can be more involved in experiments conducted in the Spacelab module. As Spacelab missions evolve, it is expected that each will be dedicated to a specific scientific discipline, such as materials processing, life sciences, or environmental observations. Use of dedicated discipline laboratories will reduce flight costs and integration requirements and will permit increased coordination among experimenters.

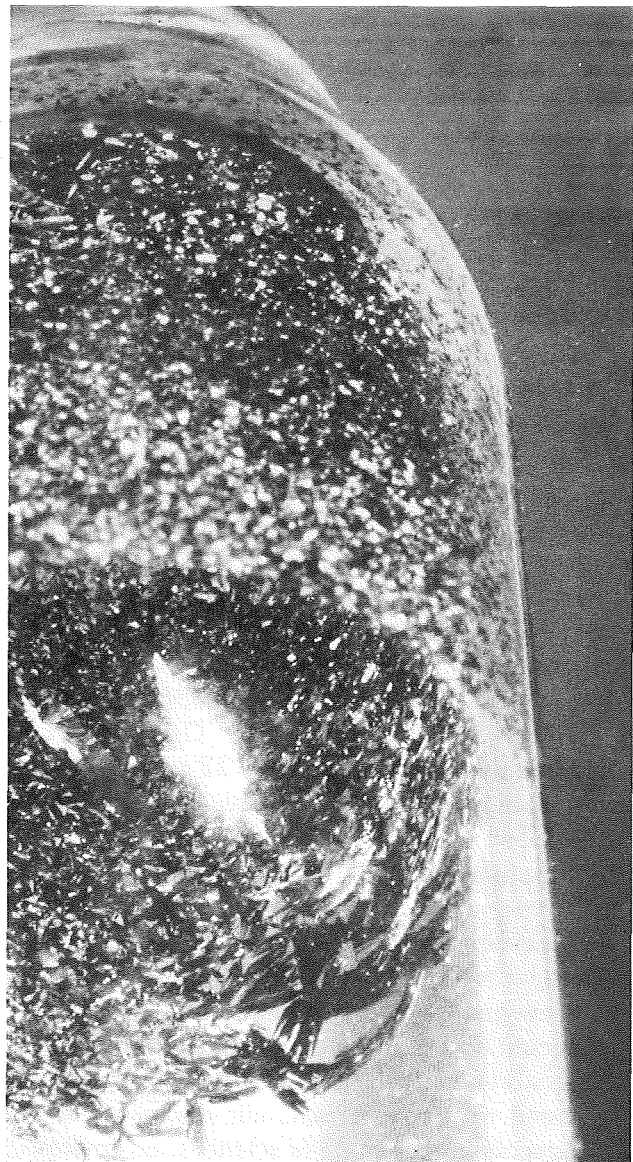
Apparatus and equipment available or under development for these experiments include many types of furnaces for crystal growth and directional solidification, electrophoresis equipment, acoustic levitators, fluid experiment systems, and vapor crystal growth systems. Several of these systems are integrated into Spacelab racks and provide advanced multi-user processing. If the existing equipment and apparatus are not suitable for an experiment, investigators may build their own, using a low-cost approach made possible by the Shuttle's opportunities for reflight.



A mercuric iodide sample will be grown by the vapor transport method during the Spacelab 3 mission.



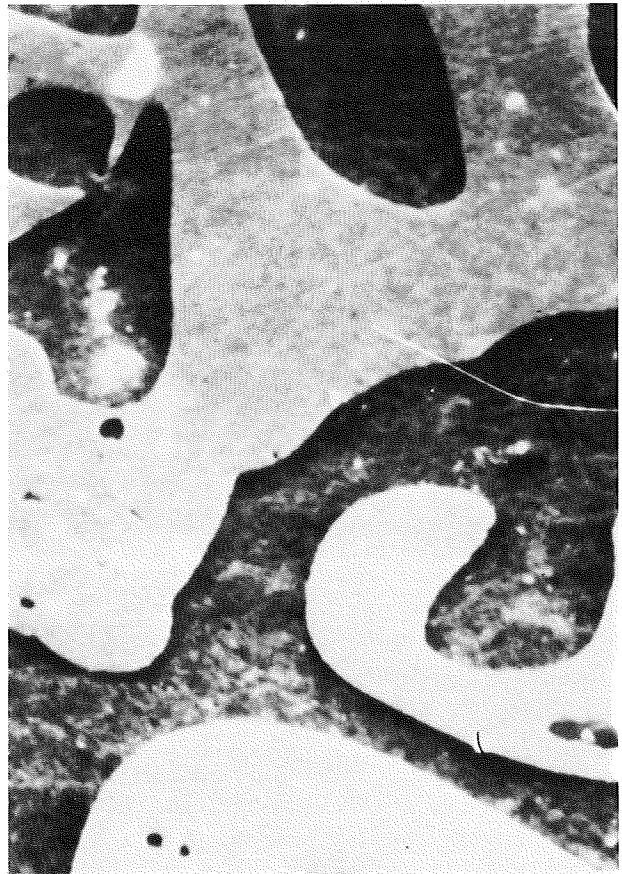
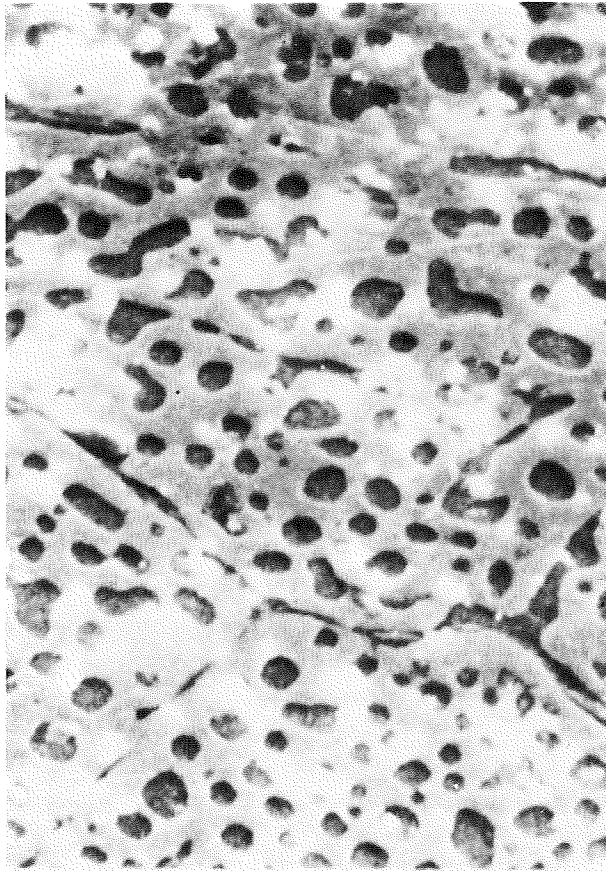
Semiconductor crystals grown by chemical vapor transport during the OSTA-2 mission (left) are larger and appear to be of much higher quality than those in the control sample processed on Earth (right).



Recent Accomplishments

Recent accomplishments in NASA's Microgravity Science and Applications program range from theoretical to ground investigations to large experiments aboard the Shuttle. The June 1983 flight of the Shuttle carried six microgravity experiments: three sponsored by the United States and three sponsored by West Germany. The U.S. experiments are:

Vapor growth of alloy-type crystals. Alloy crystals were grown by chemical vapor transport. Practical applications of this experiment could improve semiconductor technology for the electronics industry.



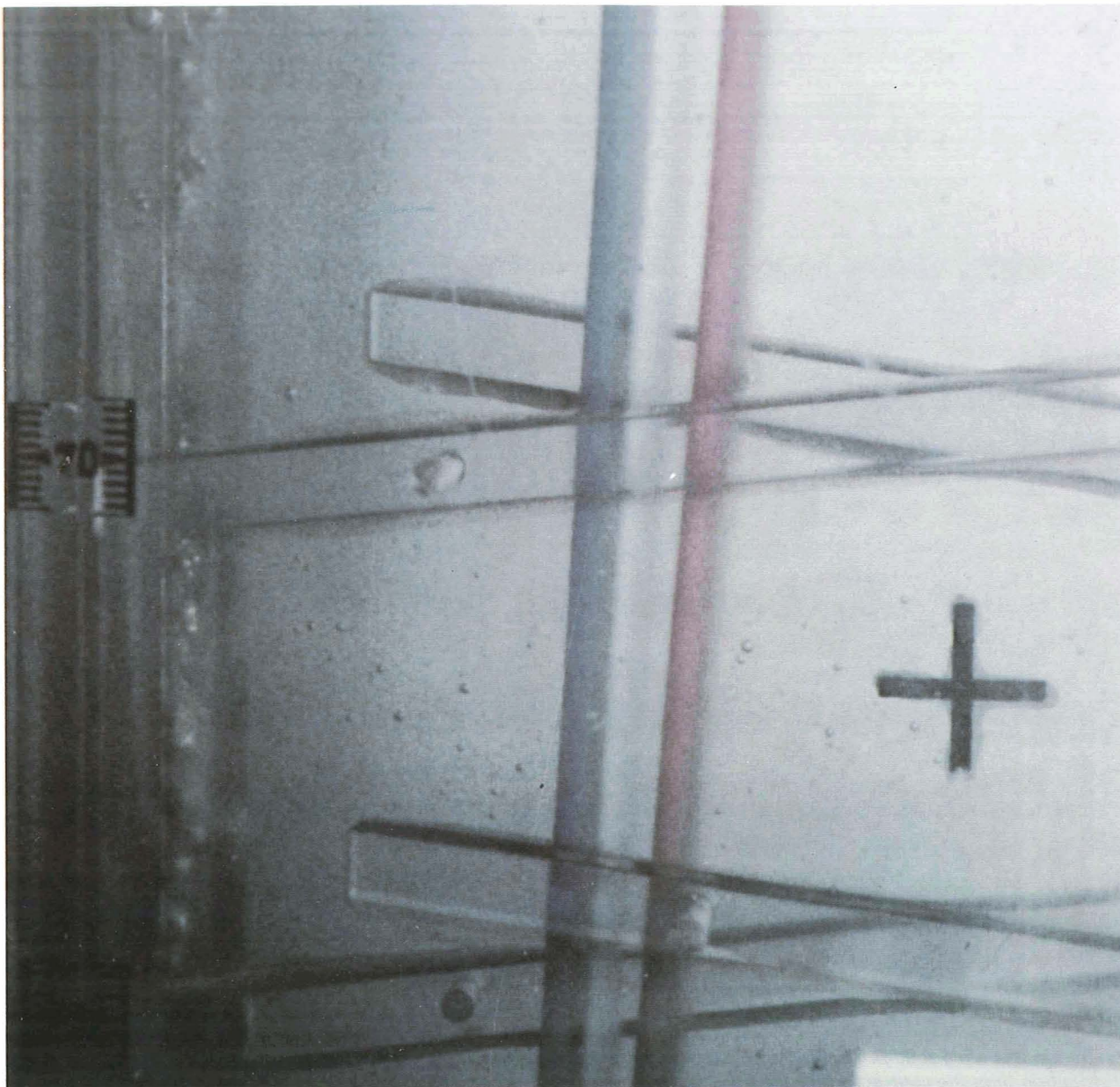
An immiscible alloy solidified in weightlessness (left) has a more even distribution than the control sample (right) processed on Earth.

Containerless processing of glass. Glass samples were injected into a furnace, positioned by acoustic pressure, melted, and cooled. This containerless processing method can be used to better understand glass formation and to improve glasses for optical and electrical applications.

Miscibility-gap materials. An immiscible alloy is a mixture that separates rapidly under gravity. Before the molten metals solidify, density differences cause the less dense metal to float on the denser metal. The miscibility problem for metals is very much like trying to mix two common liquids,

oil and water. In the zero gravity of space, however, immiscible metals can be alloyed with the desired distribution of constituents and studied. Such new alloys may lead to improved structural, electrical, and magnetic materials.

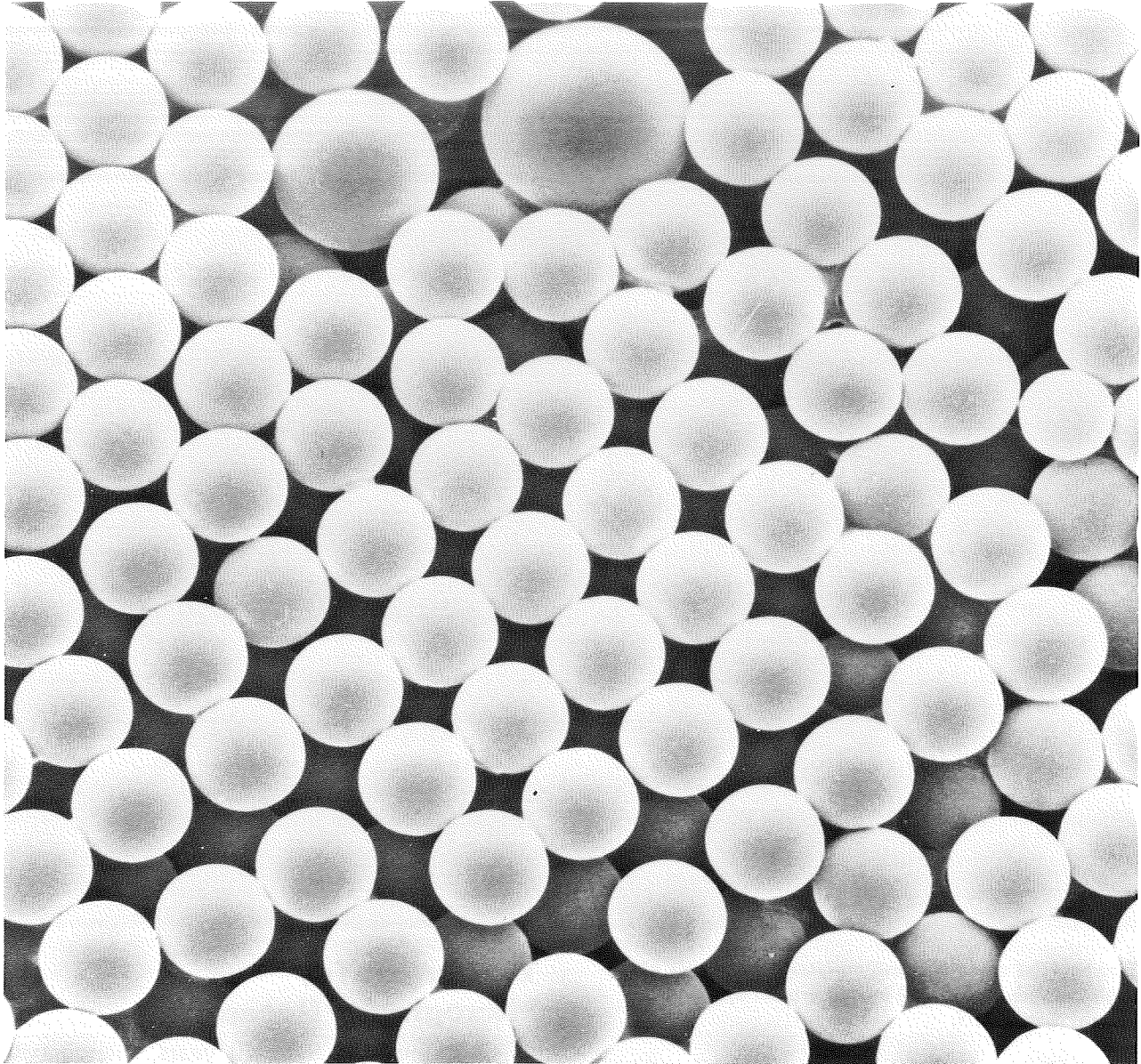
Among the German-sponsored experiments, two involved miscibility gap alloys and one involved solidification of composite materials. The fact that foreign governments and U.S. commercial investigators are willing to pay to develop the experiments they fly aboard the Shuttle indicates its importance to microgravity research.



A three-component mixture is very clearly separated during a flight of the continuous flow electrophoresis apparatus on the Space Shuttle.

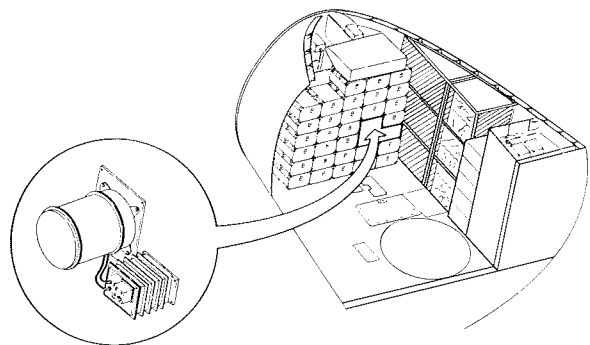
Some significant accomplishments were realized in experiments conducted in the Shuttle's mid-deck.

Continuous flow electrophoresis. A recent commercial microgravity experiment, the McDonnell Douglas continuous flow electrophoresis, is being watched closely by other researchers. The experiment offers the potential for commercial production of biological materials, such as pharmaceuticals, in space. NASA plans continued space-based research to refine and improve biological separation techniques for potential applications.



The Monodisperse Latex Reactor, located in the Space Shuttle middeck area, produces precision latex spheres.

Growth of precision latex spheres. Small, uniform latex spheres are in demand on Earth for use in calibrating electron microscopes, particle counters, and aerosol monitoring devices. A recent experiment demonstrated that weightless processing produces better formed and more uniformly sized spheres. The National Bureau of Standards has requested samples of the spheres to be used as calibration standards in their Standard Reference Material Program.





Two payload specialists will monitor the controls of the triglycine sulphate (TGS) crystal growth apparatus aboard Spacelab 3.

The Future for Microgravity Research

Over the next 5 to 10 years, microgravity research will stress both scientific and commercial goals. Products will include crystals, metals and ceramics, glasses, and biological materials. Processes will include containerless processing and fluid and chemical transport. As research in these areas develops, the benefits will become increasingly apparent on Earth: new materials, more efficient use of Earth's nonrenewable fuel resources, new pharmaceuticals, advanced computers and lasers, and better communications. Like space, the opportunities offered by microgravity science and applications are vast and are only beginning to be explored. The NASA program will evolve over the next decade to take maximum advantage of our planned Space Station capability.



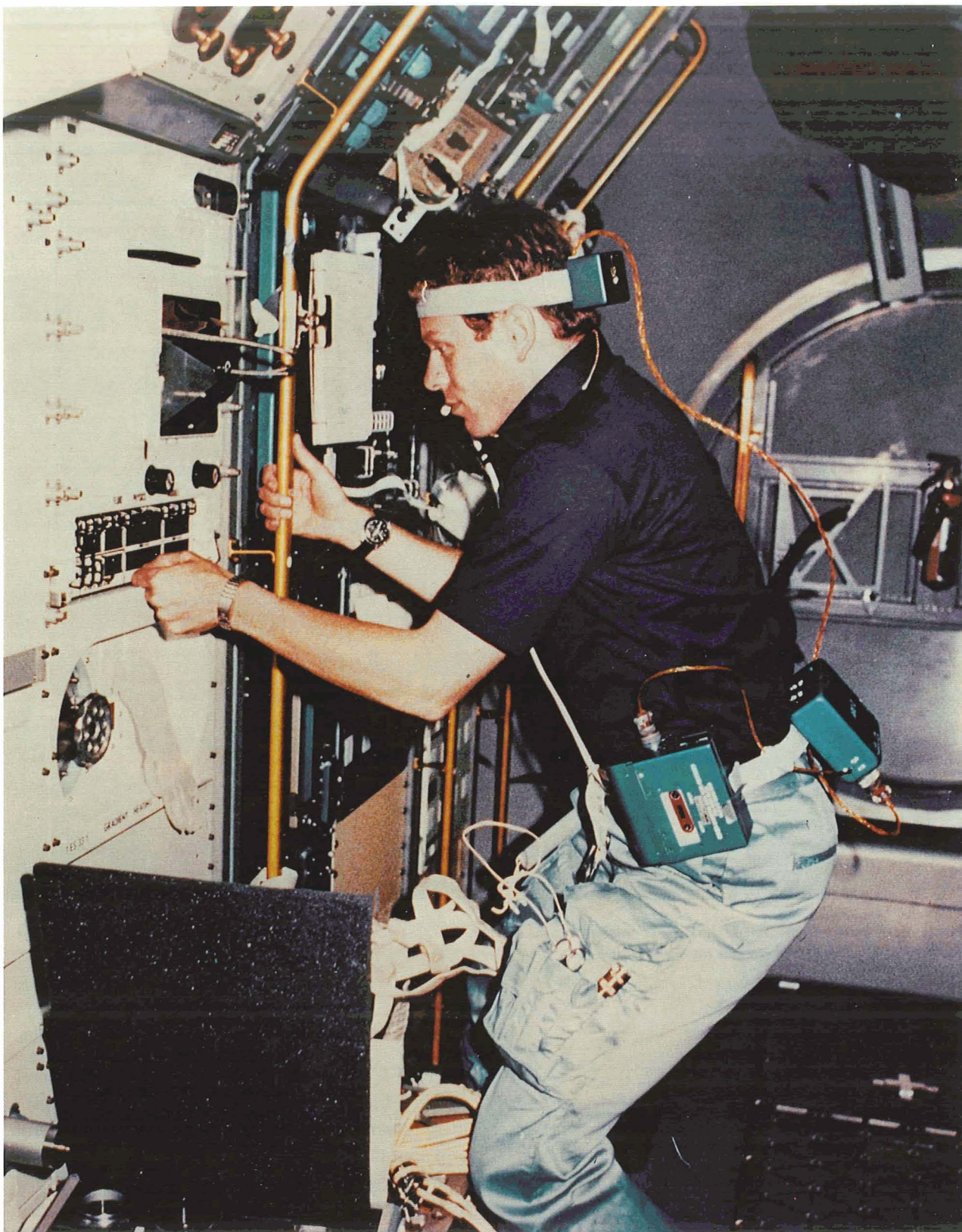
This optical system will be used for post-mission analysis of TGS crystals grown on Spacelab 3.

The NASA Program

Goal and strategy

The goal of NASA's Microgravity Science and Applications program is to use the microgravity of space to better understand physical phenomena and to control materials processes. Without such potentially adverse phenomena as convection, sedimentation, buoyancy, and container-induced contamination, the structure, properties, and performance of materials can be improved.

NASA's strategy in this program is to work upward from ground-based research (drop tubes, drop towers) to air and suborbital research (aircraft and sounding rockets) to orbital research (the Space Shuttle and Space Station). The strategy is also to involve the academic and industrial communities in flight experiments aimed at understanding processes on Earth and at developing processes uniquely suited to the microgravity of space.



Mission Specialist Lichtenberg operates a materials processing experiment on Spacelab 1.

Opportunities for Participation

NASA affords the scientific and industrial communities the widest possible opportunity to participate in its Microgravity Science and Applications program.

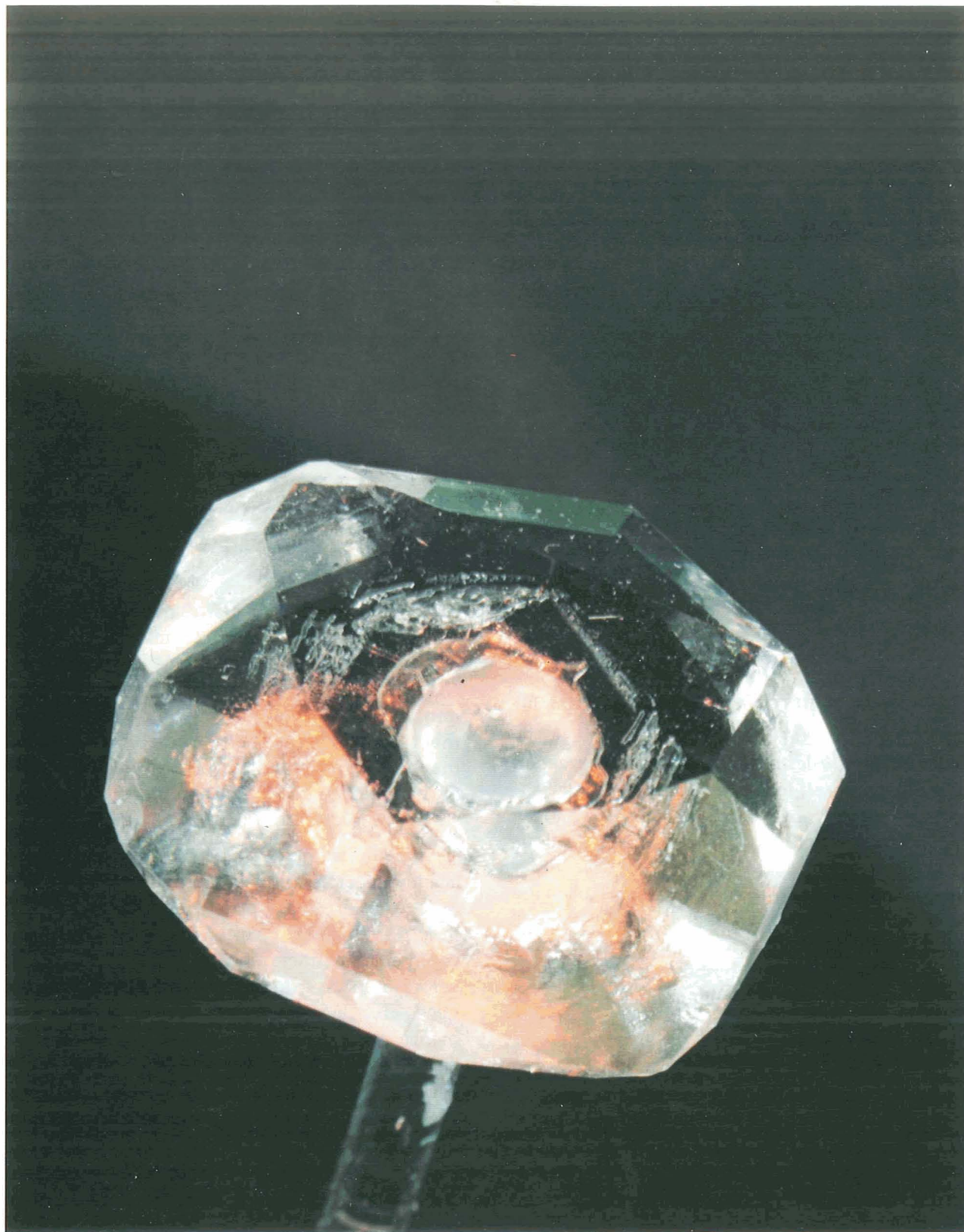
Dear colleague letters call attention to areas of continuing interest to NASA and NASA's willingness to receive unsolicited proposals in those areas. The Microgravity Science and Applications Division is presently receiving proposals under such an arrangement. A new Dear Colleague letter is expected to be issued soon that will emphasize opportunities for flight on the Shuttle. Proposals are evaluated by peer review for content, approach, and requirements in light of available resources, flight opportunities, and program needs. All data collected under Dear Colleague letters become part of the public domain. Foreign organizations also may respond, but no NASA funding is provided for foreign experiments.

In addition to Dear Colleague letters, commercial organizations can participate in the microgravity program through Joint Endeavor Agreements, and Technical Exchange Agreements, and as Industrial Guest Investigators.

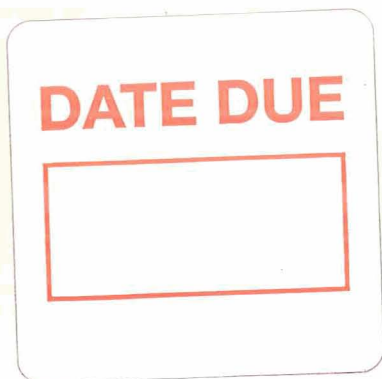
Joint endeavor agreements involve low-gravity experiments with specific commercial goals and using equipment built and funded by a commercial partner. NASA typically provides launches into space and may use the commercial equipment for its own research. The commercial data may remain proprietary. In any event, there is no exchange of funding; each partner pays his own share of the project.

Technical exchange agreements allow commercial investigators to work with NASA investigators in focused areas of applied research with essentially no additional investment on the part of the commercial partner. This research usually occurs before a space experiment has been determined necessary. Under this type of agreement, the commercial partner may use NASA ground-based facilities (drop towers, drop tubes, aircraft, and laboratories) to support a decision whether to proceed with the next step. Again, as in the Joint Endeavor Agreements, each partner pays his own costs.

Industrial guest investigators pursue topics of mutual interest with NASA researchers at NASA facilities. Salaries and expenses of the guest investigators are paid for by their commercial sponsors.



A TGS crystal will be grown from a saturated TGS solution during the Spacelab 3 mission.



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Participants

NASA's microgravity program is open to all members of the U.S. and international research and industrial communities. For U.S. researchers at universities and noncommercial institutions, funding is provided by NASA. For U.S. commercial researchers, corporate funding may be required. For non-U.S. investigations, funding is the responsibility of the participating nation or institution. NASA is proud that its program and approach have attracted participants from all three areas. NASA believes its research facilities, ranging from drop tubes to the Space Shuttle, offer individuals and organizations around the world an unparalleled opportunity to participate in microgravity science and applications. These NASA research facilities include:

Jet Propulsion Laboratory	California
Johnson Space Center	Texas
Langley Research Center	Virginia
Lewis Research Center	Ohio
Marshall Space Flight Center	Alabama

Additional information

For additional information about the NASA Microgravity Science and Applications program, write to Mr. Richard E. Halpern, Code EN-1, NASA Headquarters, Washington, DC, 20546, or call (202) 453-1490.



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